**ABSTRACT:**

1. Satellite drag variability caused by the dynamics of the upper atmosphere is a major cause of orbital specification and prediction errors in Low Earth Orbit. The problem is particularly severe during geomagnetic storms. These storms can severely degrade the accuracy of conjunction analysis between debris and spacecraft with LEO perigees and all other resident space objects.

2. We describe an assimilative upper atmosphere model (**Dragster**) capable of taking advantage of the increasing quantity of orbital data-of-opportunity represented by SmallSats.

3. We show that many CubeSats and Smallsats can be used to calibrate the state of the atmosphere.

4. This calibrated data can be used to improve global atmospheric modeling and orbital predictions for both space debris and active satellites.

**Dragster** is an assimilative tool designed to provide drag specification for the majority of resident space objects (see altitude distribution below) in the region where drag is the most relevant non-conservative orbital perturbation. This region is also populated with critical space assets (A-Train, DMSP, Iridium, ISS, etc.).

**Resident Space Objects (LEO)**

- **Dragster** assimilates orbital data from a cross-calibrated database of resident space objects. Examples of a few are illustrated on the left.

The plot below (a) shows density errors relative to the JB08 model for all validation satellites as a function of perigee altitude. 

- One year **Dragster** run using NRLMSIS-00 as the background atmospheric model (9/2015 to 1/2016 results shown below)
- Public TLEs assimilated into **Dragster**
- Special perturbations orbit solutions from high-task tracking assimilated into HASDM.
- Atmospheric-calibration tools.
- **Dragster** state vector includes both solar and geomagnetic forcing
- Test demonstrates reduction in errors over background model
- Preliminary test results demonstrate that **Dragster** can outperform or match JB08 and HASDM

**Granger** accelerometer measurements were used as a truth reference for orbit propagation. We compare in-track orbit errors associated with various atmospheric models by comparing to the **Granger** reference. The plot above (b) is a time series of 72-hr in-track orbit errors for the **GRACE** satellite near 380-400 km altitudes. The larger errors near Day of Year 80 occur during a strong geomagnetic storm.

**Results**

- Improved satellite orbit nowcast and 72h forecast
- Improvements over HASDM and JB08
- Up to three-fold improvement during storms and solar minimum
- Densities, winds and composition outputs
- Covers altitudes from 30 km to 1500 km
- Improved performance during geomagnetic storms

**Using DANDE as a validation object for assimilation results for 2015**

Preliminary test runs are performed using publically available orbits (two line elements) and NRLMSISE-00 as the background model. Forcing solutions (F10.7 and Ap) are shown in the upper plot on the right along with the empirical indices. The plot to the right shows the time-series of observed densities for the DANDE satellite along with the values specified by several models including HASDM.

**Output information feeds into existing orbit prediction and determination tools**

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**Dragster software includes detailed aerodynamic models. This allows assimilation of data from objects whose A/m ratios are not constant but vary in a predictable way. This means Dragster can ingest more data than previous atmospheric-calibration tools.**

Dragster consists of several ensemble model backgrounds (CTIPe, TIME-GCM, TIE-GCM, MSIS, JB08). Models are in turn driven by ensemble assimilation. Much like hurricane predictions, Dragster will propagate each model forward to predict the most probable trajectory of the thermospheric state and its uncertainty. Unlike tropospheric weather, the thermosphere is strongly driven by external inputs. Therefore, forecast of the input will play an important role in reducing satellite drag errors. **ASTRA** is teaming with SET to include their state-of-the-art forcing and index forecasts.